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博士后学位论文

用于获得飞行器气动导数之低速风洞绳牵引并联支撑系统

On Wire-driven Parallel Suspension Systems for Static and Dynamic Derivatives of Aircraft in Low-speed Wind Tunnels

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摘　要

为了在低速风洞试验中提取飞行器静导数，采用理论与实验相结合的方法，总结了在8根绳牵引的6自由度并联支撑系统（WDPSS-8）项目中所做的研究工作。结果表明：传统的杆支撑系统存在如支架对空气流场的影响等不可避免的缺陷；张线支撑系统非常适合用来测量低速风洞飞行器的静导数，它可提供一个大的支撑刚度，小的气流干扰和大攻角的高精度测量；绳牵引并联支撑系统为低速风洞飞行器的静导数的测量开拓了一个新思路，通过对所建造的WDPSS-8系统中的飞行器缩比模型在低速风洞试验中进行空气动力参数的测量和解算，发现绳牵引并联机构用于低速风洞试验的支撑系统是可行的。

同时指出绳牵引并联支撑系统要成功用于获取动导数的低速风洞强迫振荡实验需深入解决两大关键问题，即飞行器模型单自由度振荡运动的实现及动导数可被精确地识别出来。以该两大关键问题为目标，研究其所涉及的科学问题和技术问题，具体内容包括：在满足既定的振荡实验要求的前提下，对绳牵引并联支撑系统进行合理的机构设计；要使系统能正常工作，还要在强度、刚度、动力学特性，及测量精度和控制精度上满足要求；同时要尽量减少气动干扰；解决吹风时的绳索流固耦合问题及选择合适的六分力天平测量系统。针对所提出的8根绳牵引的6自由度绳牵引并联支撑系统WDPSS-8，开展了部分关键技术研究工作包括静刚度问题和索在层流状态下的流固耦合问题，仿真结果表明：

（1）在已选定的振荡幅值范围内，能满足支撑刚度的要求；

（2）利用ANSYS的多物理场耦合功能对WDPSS-8系统绳索的流固耦合现象时，绳索单元必须选择solid185；可使用预应力单元Prets179在绳索上施加预紧力；预紧力可以明显改善绳索的弯曲变形情况；流体域的后处理发现绳索的迎风面压力均为正值，绳索的背风面出现负压区，说明存在涡流现象。

关键词：低速风洞；绳牵引并联支撑系统；静导数；动导数；支撑刚度；流固耦合

Abstract

In order to attain the static derivatives of the aircrafts in the low-speed wind tunnel experiments, the research work about WDPSS-8(Wire-Driven Parallel Suspension System with 8 Wires) project is summarized using the method with the combination of theory and experiments. The research results have shown that, as following:

(1) The traditional strut-supported system has the unavoidable drawbacks such as the influence of the strut on the streamline flow.

(2) The cable-mounted system is very suitable for measuring the static derivatives of the aircrafts in the low-speed wind tunnel, which can provide a large suspension stiffness, small aerodynamic interference and high-precision measuring of angle of attack with a large range.

(3) Wire-driven parallel suspension system has opened a new horizon for measuring the static derivatives of the aircrafts in the low-speed wind tunnel. After the measuring and calculation of the static derivatives of the scale model of the aircrafts in the low-speed wind tunnel driven by WDPSS-8 system, it can be concluded that wire-driven parallel suspension system is available for the low-speed wind tunnel experiments.

Meanwhile it is pointed out that there are two key issues should be tackled deeply if the wire-driven parallel suspension system is used to attain the dynamic derivatives of the aircrafts for the forced oscillation experiments in the low-speed wind tunnel, i.e., the implementation of the single-degree-of-freedom oscillation of the model of aircrafts as well as the dynamic derivatives can be accurately recognized. In order to solve the two key issues, the related scientific and technological problems are summarized, as following:

(1) In the premise of satisfaction of the desired requirements of forced oscillation experiments, the mechanism designed of the wire-driven parallel suspension

system is given.

(2) The strength, stiffness, dynamic characteristics, measuring precision and control precision should be satisfied as well.

(3) Also the airflow interference of the system should be eliminated as much as possible. The coupled fluid-solid interaction between the wires and the airflow should be tackled well and the suitable 6-element force-measuring system to measure the force and moment of the streamline flow should be used.

In addition, part of key technique is investigated including the static stiffness and the problem of the coupled fluid-solid interaction between wires and the airflow for the presented WDPSS-8 system. And the simulation results have shown that, as following:

(1) The suspension stiffness of the system is satisfied among the range of the selected oscillation amplitude.

(2) When the phenomenon of the coupled fluid-solid interaction between wires and the airflow for WDPSS-8 system is analyzed using ANSYS/ Multiphysics modules, it is found that solid185 is suitable as the element of wires; pretension can be loaded in wires using Prets179, the pretension can obviously eliminate the bending deformation of wires; there exists vortex flow around wires because the wind pressure exerted on the windward side of wires is positive and that exerted on the leeward side of wires is negative.

Keywords: low-speed wind tunnel; wire-driven parallel suspension system; static derivatives; dynamic derivatives; suspension stiffness; coupled fluid-solid interaction

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